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Consensus Statement on Continuous EEG in Critically Ill Adults and Children, Part II: Personnel, Technical Specifications, and Clinical Practice

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Introduction: Critical Care Continuous EEG (CCEEG) is a common procedure to monitor brain function in patients with altered mental status in intensive care units. There is significant variability in patient populations undergoing CCEEG and in technical specifications for CCEEG performance.

Methods: The Critical Care Continuous EEG Task Force of the American Clinical Neurophysiology Society developed expert consensus recommendations on the use of CCEEG in critically ill adults and children.

Recommendations: The consensus panel describes the qualifications and responsibilities of CCEEG personnel including neurodiagnostic technologists and interpreting physicians. The panel outlines required equipment for CCEEG, including electrodes, EEG machine and amplifier specifications, equipment for polygraphic data acquisition, EEG and

video review machines, central monitoring equipment, and network, remote access, and data storage equipment. The consensus panel also describes how CCEEG should be acquired, reviewed and interpreted. The panel suggests methods for patient selection and triage; initiation of CCEEG; daily maintenance of CCEEG; electrode removal and infection control; quantitative EEG techniques; EEG and behavioral monitoring by non-physician personnel; review, interpretation, and reports; and data storage protocols.

Conclusion: Recommended qualifications for CCEEG personnel and CCEEG technical specifications will facilitate standardization of this emerging technology.

Key Words: EEG, EEG monitoring, Quantitative EEG, Seizure, Nonconvulsive seizure, Status epilepticus, Nonconvulsive status, epilepticus, Intensive care unit, Critical care, Adults, Children.

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Part I of this consensus statement described the most common indications for critical care continuous EEG (CCEEG) in adults and children. Part II covers technical aspects of CCEEG, such as qualifications of personnel performing and interpreting CCEEG, equipment, documentation, and safety. Part II also addresses commonly used CCEEG techniques for specific indications in adults and children.

Critical care continuous EEG is a rapidly evolving technology, and this statement addresses only current consensus-based recommendations for CCEEG. At this time, there are inadequate data on the impact of CCEEG on clinical outcomes to develop practice standards based on strong evidence, but existing evidence is summarized within this document. Because nonconvulsive seizures and other secondary brain injuries are often completely unrecognized without CCEEG, this document emphasizes that delayed recognition is better than no recognition. In particular, the term “monitoring” usually does not imply continuous real-time analysis and reporting of the EEG. Because of resource limitations, CCEEG is typically *acquired continuously* and *reviewed intermittently* by neurodiagnostic technologists (NDTs) for technical quality and changes in EEG patterns and also intermittently by electroencephalographers for interpretation and clinical correlation. The decision to initiate CCEEG, frequency of review, and communication of results to intensive care unit (ICU) caregivers are determined by local resources, local monitoring indications, CCEEG findings, and the patient's clinical status.

QUALIFICATIONS AND RESPONSIBILITIES OF CRITICAL CARE CONTINUOUS EEG PERSONNEL

Critical Care Continuous EEG Electroencephalographer

1. The CCEEG team should be supervised by a physician with training and experience in clinical EEG and specifically in CCEEG.
 - a. For hospitals without CCEEG electroencephalographers on staff, CCEEG oversight may be provided by CCEEG electroencephalographers within the same hospital network system.
2. Education/Certification
 - a. Physician licensure in the state or country in which CCEEG is performed.
 - b. Privileges to interpret EEGs in the hospital in which CCEEG is being performed.
 - c. Appropriate training and/or certification
 1. Certification in Clinical Neurophysiology (e.g., American Board of Psychiatry and Neurology [ABPN] in the subspecialty of Clinical Neurophysiology or American Board of Clinical Neurophysiology [ABCN]), OR
 2. Completion of 1-year fellowship training in clinical neurophysiology with concentration in EEG (at least 6 months full time) and at least 3 months of CCEEG, OR
 3. Certification in Epilepsy (e.g., ABPN in subspecialty of Epilepsy) after completion of 1-year fellowship training in clinical neurophysiology or epilepsy, which includes at least 6-month full-time exposure to EEG and at least 3 months of CCEEG, OR
 4. Certification in Neurocritical Care (e.g., United Council for Neurologic Subsidiaries [UCNS]), with at least 6-month postresidency full-time training in EEG and at least 3 months of CCEEG, OR
 5. Equivalent experience
 - d. Experience
 1. Supervised interpretation of routine EEG, video-EEG, and CCEEG. To ensure adequate exposure to a variety of EEG patterns, we suggest 500 EEGs (including routine, ambulatory, and video-EEG for epilepsy) and 100 CCEEG studies.
 2. Expertise in the operation of CCEEG equipment, including technical aspects of recording in the ICU, electrical safety, equipment troubleshooting, data recording and storage, and computer networking.
 3. Expertise in interpretation of CCEEG and video data generated in the ICU, including recognition of seizures and status epilepticus, ischemia, and the effects of acute brain injuries and drugs on EEG activity. Experience beyond routine EEG interpretation is necessary because much of the analysis involves complex rhythmic and periodic patterns and artifacts seldom encountered in a standard EEG laboratory. The analysis of CCEEG requires the simultaneous interpretation and correlation of EEG data with behavioral events and other simultaneously recorded physiologic data.
 4. Expertise in the use, yield, and limitations of quantitative EEG (QEEG) graphical trending.

3. Responsibilities
 - a. Development of policies and procedures related to CCEEG (medical director of CCEEG program only).
 - b. Analysis of pertinent segments of EEG, QEEG, and behavioral data reviewed in appropriate formats.
 - c. Timely communication of important EEG changes to the clinical management team, or other suitable integration of the EEG and clinical management teams.
 - d. Preparation of daily written CCEEG reports.
 - e. Final interpretive synthesis of CCEEG data with diagnostic and pathophysiological formulations.

Critical Care Continuous EEG Neurodiagnostic Technologists and Associated Personnel

1. Critical care continuous EEG should be performed by appropriately trained, certified, and supervised NDTs.
2. The schema provided is a suggestion for NDTs working in the ICU. Adaptations are expected based on institutional conditions, staffing, and workflow requirements. We recommend that at least one NDT performing CCEEG have training, credentialing, and/or experience at the level of Neurodiagnostic Technology Specialist (NDTS) I ICU (see point 6 below).
3. Neurodiagnostic Technologist I (Trainee)
 - a. Education/certification
 1. Associate's degree OR
 2. Enrolled in Neurodiagnostic program
 - b. Responsibilities
 1. Maintains recording integrity (replaces or re-gels electrodes, restarts studies, troubleshoots basic equipment errors).
 2. Performs 10/20 measure and applies electrodes under the direct supervision of NDT III or NDTS I–II (see points 5, 6, and 7 in this section below) according to facility policy.
 3. Removes electrodes, including collodion removal with acetone, under supervision.
 4. In emergency situations, may independently place limited electrode arrays using premeasured caps or nets, with self-adhesive, disk, or needle electrodes.
4. Neurodiagnostic Technologist II
 - a. Education/certification
 1. Meets ASET—The Neurodiagnostic Society National Competencies for Performing an Electroencephalogram.
 2. Eligible for registration in EEG (Registered EEG Technologist, R. EEG T.) by ABRET Neurodiagnostic Certification and Accreditation.
 3. Six months of NDT experience.
 - b. Responsibilities
 1. All responsibilities of NDT I.
 2. Performs CCEEG recording under direct supervision of NDT III or NDTS I–II (see points 5, 6, and 7 below).
5. Neurodiagnostic Technologist III
 - a. Education/certification
 1. Registration in EEG (Registered EEG Technologist, R. EEG T.) by ABRET.
 2. Associate's degree in Electroneurodiagnostic Technology or equivalent. Appropriate clinical experience may be substituted for this degree.

- b. Responsibilities
1. All responsibilities of NDT II.
 2. Performs CCEEG recording independently.
 3. Supervises NDTs I–II if needed.
6. Neurodiagnostic Technology Specialist I ICU
- a. Education/certification
1. Certification in Long-Term Monitoring by ABRET
 2. Meets ASET National Competency Skill Standards for CCEEG Monitoring (2008).
 3. Three years of experience as an NDT, including 1-year experience in CCEEG.
 - a) Special training in the use, routine maintenance, and troubleshooting of CCEEG equipment in the ICU, with particular emphasis on techniques for monitoring the integrity of data recording, electrical safety, and infection control.
 - b) Special training and resultant expertise in the recognition of ictal and interictal electrographic patterns and in their differentiation from artifacts.
 - c) Special training and resultant expertise in QEEG analysis and patterns suggestive of neurologic deterioration.
 - d) Special training and resultant expertise in the recognition of clinical seizures and seizure-related medical emergencies.
- b. Responsibilities
1. All responsibilities of NDT III.
 2. Technical operation and supervision of CCEEG studies (e.g., patient preparation, equipment setup, and data recording).
 3. Review of QEEG trends and selection of segments for later analysis, under the supervision of a physician.
 4. Notification to physician electroencephalographer of changes in CCEEG activity that may reflect deterioration in brain function.
7. Neurodiagnostic Technology Specialist II ICU
- a. Education/certification
1. Registration in Certification in Long-Term Monitoring by ABRET.
 2. Meets ASET National Competency Skill Standards for CCEEG Monitoring (2008).
 3. Three years of experience post–Certification in Long-Term Monitoring credential.
 - a) Same special training as NDTs I ICU.
- b. Responsibilities
1. All responsibilities of NDTs I ICU.
 2. Development of technical policies and procedures related to CCEEG in conjunction with physician electroencephalographer.
 3. Supervision and training of CCEEG-associated personnel, including NDTs, nurses, and other ICU staff.
8. Neurodiagnostic Laboratory Assistant
- a. EEG Assistants perform some limited EEG tasks, typically during hours in which NDTs are not available in the hospital. In some cases, EEG Assistants may be other medical personnel (e.g., patient care assistants, ICU nurses, etc.) who have been trained in specific EEG tasks. The EEG Assistant should be able to communicate with a qualified NDT, preferably NDTs, who can connect and review EEG remotely.
- b. Education/certification
1. Variable by center. At least high school diploma.
 2. If EEG Assistants are used, the center should have a written policy and procedure describing the types of tasks that can be performed, as well as requirements for training and determination of competency (Seiler et al., 2012).
- c. Responsibilities
1. Typical tasks include reapplying or re-gelling loose or detached electrodes, removing electrodes, performing emergency EEG using limited electrode array templates or caps, or monitoring video recordings for changes suggestive of clinical seizures.
9. Critical care continuous EEG observer
- a. Critical care continuous EEG observers are not NDTs and cannot substitute for the EEG review functions of qualified NDTs. Their role is to continuously review video and sometimes QEEG trends and serve as “first responders,” notifying trained NDT and physician staff about clinical and/or trend changes. The EEG Assistant should be able to communicate with a qualified NDT, preferably NDTs, who can connect and review EEG remotely.
- b. Education/certification
1. High school diploma or equivalent.
 2. Training in recognition of clinical ictal behavior and interaction with patients during seizures to assess level of consciousness.
 3. May include training in recognition of important changes on graphical displays of QEEG.
 4. May include training in maintaining recording integrity (reapplying or re-gelling loose or detached electrodes).
- c. Responsibilities
1. Patient and QEEG observation (direct or several patients at a time through video monitoring) to identify and note ictal events, interact with patients during seizures, and alert appropriate personnel (e.g., physician, NDTs, nursing staff) to the occurrence of changes in QEEG trends.
 2. Adjust video cameras to keep patient in view and ensure that EEG and video are continuously recorded, calling appropriate personnel to assist when problems occur.
- d. Intensive care unit nurses may serve in this role, including alerting physicians to events that require physician review and changes in patient care.

CRITICAL CARE CONTINUOUS EEG MONITORING EQUIPMENT

ACNS Guidelines for Performing Clinical EEG in Adults and Children

The Task Force recommends that CCEEG meets the technical specifications described in ACNS guidelines for performing clinical EEG in adults and children (American Clinical Neurophysiology Society 2006a, 2006b).

Electrodes

1. Disk or cup electrodes (gold, silver, or silver chloride) are typically used for CCEEG. Electrodes with a central hole are best to permit periodic refilling with electrode conductive gel.
 - a. When possible, computed tomography (CT)- and/or MRI-compatible electrodes should be used, especially if the patient is likely to require repeated neuroimaging studies (Vulliemoz et al., 2009). More than 50% of patients will require neuroimaging with MRI or CT during the course of CCEEG monitoring. These electrodes (e.g., conductive plastic electrodes, subdermal wire electrodes) can remain in place during imaging, reducing time spent in removing and reapplying electrodes, and may also reduce skin breakdown caused by frequent electrode removal and reapplication.
 - b. For CT compatibility, electrodes must be low density, non-metal to avoid “starburst” artifact, and are typically carbon- or silver-impregnated plastic. Connectors for some electrodes, including needle electrodes, may contain metal that causes streak artifact on CT or degrades the quality of angiograms.
 - c. For MRI compatibility, specialized electrodes and techniques are needed to avoid thermal or radiofrequency burns. These include nonmagnetic electrodes, short electrode wires, specialized connectors, and careful avoidance of electrode wire coils (Mirsattari et al., 2004).
2. Subdermal needle electrodes. Single-use disposable stainless steel needle electrodes can be applied rapidly and do not require scalp abrasion. Needle electrodes have inferior recording characteristics (attenuate low-frequency signals) and pose a risk for needlestick injury to ICU personnel if dislodged. They may be appropriate for rapid application and brief recording in some comatose patients (Kolls et al., 2012) but are generally not recommended for prolonged CCEEG recordings. Needle electrodes may cause some artifact on CT and angiography and are not MRI compatible.
3. Subdermal wire electrodes. Subdermal wire electrodes are single-use disposable Teflon-coated silver wire with a 3- to 5-mm silver-chlorided tip (Ives, 2005; Mirsattari et al., 2004; Vulliemoz et al., 2009). They may reduce skin breakdown and provide superior recording characteristics compared with disk electrodes for patients requiring very prolonged CCEEG monitoring (Martz et al., 2009). They cause little artifact on CT and angiography and can be MRI compatible with specialized connectors.
4. Electrode cap and/or template systems may be used when rapid initiation of EEG electrodes is essential or when NDTs are not immediately available. Caps must be disinfected between each use, may increase risk of pressure injury from electrodes, and may be limited by the presence of scalp wounds or other cranial monitoring devices. Single-use disposable templates can be placed quickly and reliably and limit infection risk.
5. Scalp electrodes should be applied with proper infection control policies and procedures. Disposable single-use electrodes should be considered, especially for patients with scalp wounds or recent neurosurgical procedures. These electrodes are more expensive than traditional EEG electrodes.
6. Intracranial electrodes. Subdural grid or strip electrodes for CCEEG monitoring have been used to identify electrographic seizures and cortical sustained depolarization in critically ill patients but are not in routine clinical use

(Hartings et al., 2011, 2013). Intracranial depth electrodes have been used in combination with FDA-approved intracranial monitoring devices but are not in routine clinical use (Stuart et al., 2010a, 2010b; Waziri et al., 2009).

Critical Care Continuous EEG Acquisition Machines

1. Critical care continuous EEG amplifiers, analog-to-digital converters, central processing units, software, and monitors should meet ACNS recommended specifications (American Clinical Neurophysiology Society 2006a, 2006b, 2006d) with the following additional points for CCEEG.
2. Amplifiers: Wirelessly connected amplifiers can be placed at a distance from the patient’s head and may be preferred in the cluttered ICU environment. Some amplifiers are battery powered and contain internal storage, allowing continued EEG recording even when patients leave the ICU for other procedures.
3. Critical care continuous EEG acquisition computers should have sufficient processing capability to perform simultaneous EEG and video acquisition, QEEG analysis, and spike/seizure detection.
4. Hard drive capacity should be sufficient for storage of at least 24 hours of continuous video and EEG data. Most currently available systems far exceed this capability. Typical equipment can record and locally store 5 to 7 days of 32 or more channels of EEG plus digital video.
5. Critical care continuous EEG acquisition machines can be either fixed or portable. Fixed installations often have advantages in terms of video recording, as cameras are mounted high on the wall. EEG equipment is also away from the patient and out of the way of ICU personnel. However, when EEG machines are fixed, patients requiring CCEEG have to be moved into rooms with the EEG equipment, which can result in delays in initiation of monitoring. Portable carts should have a small footprint to minimize disruption of workflow in the ICU room.
6. Video and cameras: Concurrent synchronized video recording is recommended for CCEEG. Video recording allows correlation of clinical behavior (e.g., seizures, changes in level of alertness, identification of alerting stimuli) with EEG features. Review of video is also an excellent method for identification of artifact in CCEEG studies (Tatum et al., 2011).
 - a. Equipment for video recording varies extensively in features, picture quality, and cost, ranging from small portable monochrome cameras to fixed multi-camera installations with full remote control capabilities. Patients in the ICU are not likely to move themselves off camera, so fixed wide-angle cameras may be a low-cost solution. Accurate resolution of fine motor movements or subtle seizures, however, will likely require high-resolution color cameras with the ability to move and zoom the camera to body regions of interest. The video stream is time synchronized with the EEG data.
 - b. Cameras should be mounted on the wall or on a tall pole to allow the patient to be visualized even when bedside caregivers are in the room.
 - c. IP addressable cameras allow remote pan/tilt and sometimes focus/zoom from remote locations over standard network cables. This reduces costs, as no

specialized cables need to be run. IP cameras may be appropriate for both fixed and mobile acquisition machines.

- d. Video should be recorded in as high resolution as feasible with appropriate compression algorithms for sufficient storage and transportability. MPEG-4 format at 320×240 or 640×480 pixel resolution is commonly used. Full HD quality video is now available but generates extremely large file sizes (12–20 GB/24 hours) and is often not needed for CCEEG recordings.
7. Audio recording: In addition to the video image of patient behavior, an audio recording can alert monitoring technologists to clinical episodes and allow assessment of behavior and neurological function as described by CCEEG personnel attending to the patient during the episode.
8. Because the ability to remotely view CCEEG is essential, all machines should have network connectivity and network interface card with 100 megabits per second minimum. Rapid EEG and video review will usually require at least 1 gigabit per second. Wireless connectivity can be used when wired network connections are not available but may lack sufficient bandwidth for transfer of video recordings.
9. Event marking: Systems should include a patient event button for patient, family, and staff to push when clinical events occur, as well as ability to type comments directly onto the EEG tracing.
10. Isolated power supplies and electrically isolated jack boxes should be used to protect electrically sensitive patients from injury.
11. User-friendly hardware and software features can substantially improve the efficiency and quality of CCEEG. The following features may be helpful and should be considered when evaluating and purchasing EEG equipment.
 - a. Ability for ICU personnel to annotate ongoing records. Simplified user interfaces and touch screen displays often improve usability for ICU personnel.
 - b. Artifact/bad channel displays.
 - c. Automatic recovery mode (if machine is accidentally unplugged or malfunctions, automatically restarts, and reacquires data when turned back on).
 - d. Automatic start/stop study (by time or by number of hours recorded).
 - e. Event detection: Methods of detection of clinical events and seizures include (1) patient- or nurse-activated pushbuttons as above, (2) automated spike and seizure detection programs, although these have not been validated for ICU patients, (3) graphical displays of QEEG (trends, see Section V.E), and (4) alarms or automated alerts for events through audio, video, pager, or e-mail.
 - f. Security: All computers should be Health Insurance Portability and Accountability Act (HIPAA) compliant and meet local information technology security standards. Password-protected transparent screen locks can prevent non-ICU personnel from interfering with recording but still allow viewing of ongoing recording. Acquisition computers left in patient rooms should be locked to prevent access to hard drives and be secured with cable locks to the acquisition machine frame. Laptop computers and external drives should be locked and encrypted.

Equipment for Polygraphic Data Acquisition

1. Polygraphic and multimodality data may be useful in interpretation of CCEEG, recognition of artifacts, and confirmation of changes in brain function by correlation with other physiologic parameters (Miller, 2012; Tatum et al., 2011; Vespa, 2005; Wartenberg et al., 2007). Physiologic data streams should be time synchronized with EEG. The details of data acquisition for physiologic parameters other than EEG are beyond the scope of this consensus statement.
2. Types of polygraphic or multimodality recording include electrooculogram, electromyogram, electrocardiogram, body movement monitors or actigraphs, temperature, blood pressure (noninvasive or invasive), respiratory effort, respiratory airflow, oxygen saturation, intracranial pressure, transcranial Doppler, evoked potentials, brain tissue oxygenation, cerebral microdialysis, and near-infrared spectroscopy.
3. Integration of polygraphic data with CCEEG: Lack of standardization and data exchange formats makes multimodality data collection and storage difficult. Electrodes, specialized devices, or transducers can be connected directly to the CCEEG machine. This is the most common way to record electrooculogram, electromyogram, and electrocardiogram. Specialized devices and transducers may require DC amplifier inputs. Most other physiologic data are obtained and displayed on ICU monitors, so use of another device connected to the CCEEG machine is redundant and potentially costly. Alternatively, the output from ICU monitoring devices can be duplicated and output to the CCEEG machine. This may require specialized cables to output signals from ICU monitors to CCEEG machines. A variety of vendors make ICU monitors, and there is little standardization of device types and inputs. Post hoc or real-time integration of data files from ICU monitor and CCEEG machine usually requires custom software solutions or data export into existing open source formats.

EEG and Video Review Machines

1. Review is typically performed at a review station or computer separate from acquisition machines.
2. Display monitors for review: The current optimal standards are 1600×1200 pixels with a screen diagonal size of 20 inches or more. Dual monitors may be helpful for concurrent display of raw EEG tracings and QEEG trends. Monitors for remote review may have lower resolution, but these may introduce aliasing artifacts (Epstein, 2003).
3. Software features useful for review
 - a. Remote control capabilities, including pan-tilt-zoom camera control and the ability to review and control live ongoing studies and alter recording parameters from remote locations.
 - b. Ability to filter EEG data by type of events.
 - c. Databases and report generation software: These allow efficient organization of patient and study information, facilitate archiving and retrieval of data, allow reports to be saved as part of the EEG record, and, if HL7 compliant, can be interfaced with electronic medical records.
 - d. Security: Systems should be HIPAA compliant and meet local information technology security standards.

Central Monitoring Equipment

1. Nurse or technologist monitoring stations are specialized hardware and software solutions that allow simultaneous viewing of video streams, and sometimes EEG and QEEG trends, for a number of patients on a single monitor or cluster of monitors. These systems frequently include software to allow movement of cameras, audio and/or video alerts when patient pushbuttons are activated or automated seizure detection algorithms, and intercoms for interaction with patients during clinical events. Although no studies have directly addressed the clinical utility of central monitoring, the fact that many patients can be monitored simultaneously likely decreases the costs of monitoring. See Section V.E.6 for further details.

Networking, Remote Access, and Data Storage Equipment

1. Because the goal of CCEEG is to rapidly identify seizures and ischemia, CCEEG data should be available for review by personnel both within and outside the hospital. This requires robust networking and remote access capabilities.
2. Hospital network: The ICU should be supported by a robust network backbone with sufficient capacity to transmit EEG and video data from acquisition systems and/or servers to review stations without perceptible degradation of review speed. The backbone should be fully redundant, so that clinical care CCEEG monitoring services are not vulnerable to single component failures. Fully hardwired networks are preferred; the network interface speed for acquisition devices should be at least 100 megabits per second (Mbps). Wireless connection may be acceptable, provided that the hospital's wireless infrastructure is adequate to support high-reliability continuous data transfer at speeds sufficient for video/EEG monitoring. Wireless networks designed for applications with lower bandwidth and reliability requirements, such as record keeping and administrative functions, may be inadequate. The bandwidth of a wireless access point is shared by all simultaneously connected devices (similar to a hub on a wired network), and permanent as well as mobile (e.g., x-ray machines) physical obstacles can create "dead spots" where wireless communication can fail or can be slow or unreliable; the quantity, type, and positioning of wireless access points in the ICU should be sufficient to mitigate these concerns.
3. Acquisition machines: If EEG/Video data are stored in real time to a central server (rather than locally on the acquisition machine), the acquisition system should be able to automatically detect loss of ability to write to the server and seamlessly revert to local storage with no loss of data. Ideally, the system should also be able to automatically detect restoration of connectivity, upload locally buffered data, and seamlessly resume real-time data upload.
4. Remote access: Each hospital will likely have specific hardware and software available for remote access solutions. Because remote access potentially poses a risk to security of patient data, hospitals typically impose stringent security protocols governing use of these systems. Solutions vary widely in ease of implementation and cost.

Critical care continuous EEG programs should work with their hospital's information technology department to determine which solution has optimal ease of use, security, and cost.

- a. Ad-hoc secure remote desktop connections: Software packages such as GoToMyPc or LogMeIn can provide a remote PC (or tablet computer) with a real-time copy of the screen of a desktop CCEEG reading station in the hospital. These systems can be secure, but this security is critically dependent on proper implementation. If this type of system is used for remote CCEEG monitoring, it is suggested that its be implemented by, or under the supervision of, the hospital's information technology department.
 - b. Virtual private network: Hospitals commonly use virtual private networks (VPNs) to provide for remote access to resources within the institution's network. A VPN establishes a secure encrypted "tunnel" from the remote computer, through the Internet, to behind the hospital's firewall, so that the outside computer can appear to be part of the hospital's network. Remote CCEEG monitoring may be implemented over a VPN in 2 ways:
 1. The actual EEG data are sent over the Internet and displayed on the remote computer by standard review software. Each remote computer must have the EEG review software installed. Because Internet speeds are likely to be slower than hospital network speed, online real-time VPN review may be slow. Downloading the EEG files to the local computer before review allows for fast review speed.
 2. Remote desktop software may be used to provide a remote screen view, much like with secure remote desktop connections, above, but relying on the VPN tunnel for security. A variety of remote desktop solutions are available, including the remote desktop protocol built into Microsoft Windows.
 - c. Server-based remote desktop systems: Systems such as Windows Terminal Services or Citrix provide remote desktop access, but to "virtual desktops" running on the hospital's server. The EEG review software runs on the server, and only screen images are sent over the Internet. These systems can provide reliable centrally administered review platform and offer greater security than a VPN. They can be costly, including the servers and software license fees.
5. Data storage equipment: File servers can provide a central repository for CCEEG and video data files, allowing multiple users to connect to the same data from multiple locations. Critical care continuous EEG file servers typically run database software (generally supplied by the EEG vendor) that keeps track of patient identifying information and data locations. File servers should have adequate storage capacity (data generated in 24 hours by 1 CCEEG acquisition machine × number of acquisition machines × number of days data are stored before archiving). Example: 12 GB/day (video + EEG) × 8 machines × 30 days = 2880 GB or ~3 TB. Servers use specialized hardware, including arrays of high-speed disk drives, to provide reliable high-speed access to large quantities of data, even under conditions of heavy load. Servers selected for CCEEG monitoring should be specified to have sufficient and data throughput to support rapid uninterrupted EEG/video data review, even when the maximum number of simultaneously

active acquisition and review stations are in use. Servers should also be specified to provide safeguards against data loss. These include appropriate configuration of disk arrays to provide data redundancy, as well as offline backup.

6. Archiving equipment: Video data account for the bulk of CCEEG data storage requirements, particularly with newer high-resolution cameras; when the study is ready for archiving, most video data typically do not need to be retained and can be discarded. Depending on available resources and the institution's archive storage requirements, archived studies may be retained online, either on the primary data server or on a lower performance online storage device, or offline using external DVDs or hard drives. Archiving software should have the capability of operating automatically, without negatively impacting server performance for CCEEG review functions. It should include the ability to export data to long-term storage media and to export to open source EEG data formats ACNS 2014. It is important to consider applicable data retention requirements when implementing CCEEG data archive solutions. See CRITICAL CARE CONTINUOUS EEG PROCEDURES: CCEEG Data Storage Protocols for archiving procedures.

CRITICAL CARE CONTINUOUS EEG PROCEDURES

Patient Selection and Triage

1. Critical care continuous EEG programs should have written pathways outlining the indications, urgency, and duration of CCEEG, based on typical patient populations encountered and availability of local resources. Even in well-established CCEEG programs, availability of staff and equipment may limit the number of patients who can be recorded at one time. Written protocols can help to facilitate CCEEG monitoring, ensuring that patients who meet criteria for CCEEG are referred for testing and establishing parameters for starting and stopping tests. Pathways for CCEEG monitoring are generally developed by a team including both electroencephalographers and critical care physicians. They define patient populations, by disease and by illness severity, in which CCEEG should be ordered and initiated in a specific hospital setting, as well as the typical duration of CCEEG.
2. Example pathways for patient populations in whom CCEEG is typically recommended can be found in Table 1.

Initiation of Critical Care Continuous EEG

1. Under ideal conditions, CCEEG should be available 24 hours a day 7 days per week, with electrodes applied and EEG recorded by NDTs with rapid interpretation by an experienced electroencephalographer, as described in qualifications and responsibilities of critical care continuous eeg personnel. Unfortunately, CCEEG is not continuously available in all hospitals and may take several hours to initiate, record, and interpret even when the service is available (Abend et al., 2010; Quigg et al., 2001; Sanchez et al., 2013a; Sanchez et al., 2013b). Once a CCEEG program is established, demand for off-hours and urgent EEG increases and usually requires that an

TABLE 1. Example Pathways for Patient Populations Undergoing CCEEG

Known NCS or NCSE

Illness severity: subclinical or refractory seizures and status epilepticus
 Purpose of monitoring: identify NCS, confirm treatment efficacy
 Recording duration
 Suspected NCS: discontinue after 24–48 hours if no seizures occur
 Confirmed NCS: discontinue 24 hours after the last seizure occurs
 Refractory NCSE: discontinue 24 hours after cIV-ASDs are stopped if no seizures recur
 QEEG: seizure identification methods, measures of burst suppression

Traumatic brain injury

Illness severity: altered mental status and/or intracranial hemorrhage
 Purpose of monitoring: identify NCS
 Recording duration: begin as soon as feasible, discontinue after 24–48 hours if no seizures occur; can be requested for additional 48 hours as sedating medications weaned
 QEEG: seizure identification methods

Intracerebral hemorrhage

Illness severity: any alteration in awareness
 Purpose of monitoring: identify NCS
 Recording duration: begin as soon as feasible, discontinue after 24–48 hours if no seizures identified; can be requested for additional 48 hours if sedating medications weaned
 QEEG: seizure identification methods

Hypothermia after cardiopulmonary arrest

Illness severity: coma after cardiac arrest undergoing hypothermia protocol (altered mental status after cardiopulmonary arrest)
 Purpose of monitoring: identify NCS, prognostication
 Recording duration: begin as soon as feasible, preferably before hypothermia is initiated; discontinue 24 hours after patients reach normothermia if no seizures occur
 QEEG: seizure identification methods, measures of burst suppression

Aneurysmal SAH

Illness severity: Fisher grade 3 or 3/4, Hunt and Hess grades 3, 4, and 5
 Purpose of monitoring: identify ischemia/vasospasm; identify NCS
 Recording duration: begin on SAH day 2 after treatment of aneurysm, optimal duration not identified but if resources allow, consider recording through day 14 or discharge from the ICU
 QEEG: seizure identification methods, ischemia identification methods
 Several other patient populations may be candidates for CCEEG, but there is limited evidence supporting the benefit of CCEEG. These requests should be considered on an individual basis, with examples below:
 Management of elevated intracranial pressure; monitoring level of sedation

Illness severity: ICU patient requiring sedation with continuous intravenous anesthetic agent
 Purpose of monitoring: titration of sedation to minimize adverse hemodynamic effects
 Recording duration: need for continued monitoring should be discussed with EEG team daily
 QEEG: seizure identification methods, measures of burst suppression

Other acutely ill neurologic patients

Illness severity: coma or obtundation
 Post neurosurgical procedure with altered mental status to identify NCS
 Large ischemic stroke to identify worsening ischemia
 Purpose of monitoring: varies with indication
 Monitoring duration: need for continued monitoring should be discussed with EEG team daily
 QEEG: seizure identification methods, measures of burst suppression, ischemia methods

CCEEG, critical care continuous EEG; cIV ASD, continuous intravenous antiseizure drug; NCS, nonconvulsive seizure; NCSE, nonconvulsive status epilepticus; QEEG, quantitative EEG; ICU, intensive care unit; SAH, subarachnoid hemorrhage.

NDT be in the hospital for at least the majority of the day, including weekends.

- a. In some cases, NDTs may take call from home. If so, patient selection written pathways should clearly indicate which indications justify calling in an NDT to initiate CCEEG.
 - b. Limited electrode arrays can be applied by trained neurology residents, nursing staff, or patient care technologists, but interpretable recordings may be difficult to obtain by non-NDT staff. Template systems, such as elastic nets with holes for standard electrode positions, or pre-gelled “peel-and-stick” plastic strips may improve EEG quality, time to study completion, and overall costs (Kolls et al., 2014; Ziai et al., 2012).
 - c. Additional research is necessary to determine the utility and cost effectiveness of providing continuous availability of CCEEG.
2. Electrode Types
- a. A variety of different types of electrodes is available for use in the ICU (Section IV.B). Critical care continuous EEG programs should consider electrode cost, ease of use, time for application, imaging compatibility, durability, and recording characteristics when selecting electrodes for ICU patients.
 - b. Adoption of a uniform electrode type may be helpful.
 1. Critical care continuous EEG staff can more easily train nurses and other staff about electrode application, procedures for emergency removal, and safety.
 2. Safety for neuroimaging, particularly MRI, is enhanced with uniform electrodes.
3. Electrode application
- a. Disk electrodes: Application by electrode paste alone is not recommended. Collodion technique is the preferred method to ensure a stable long-term recording but may not be possible in all ICU locations. Collodion use is restricted in some ICUs because of inadequate ventilation. Collodion is typically removed with acetone, which poses a risk for injury to eyes and skin of both patients and staff, as well as damage to other intracranial monitoring devices, some plastics, and tubing. EC2 paste, Tegaderm, and cyanoacrylate may substitute for collodion. Disk electrodes may cause pressure breakdown in comatose patients undergoing prolonged CCEEG, especially in posterior head regions. A cushion or pad may be used under disk electrodes to reduce pressure breakdown of the skin, and the head frequently rotated and elevated with a neck roll to reduce prolonged pressure on the same scalp locations.
 - b. Subdermal needle electrodes: The scalp is cleaned thoroughly with presurgical scrub. Needle electrodes are inserted just beneath the skin, parallel to the surface of the scalp. The full length of the needle should be embedded. Needle electrodes should be secured with collodion or EC2 paste. They are often used as part of a rapid application kit and can be secured to the head net. Needle electrodes are not appropriate for awake patients, infants, young children, patients with suspected viral hepatitis or Creutzfeldt–Jakob disease, or prolonged recording.
 - c. Subdermal wire electrodes: Subdermal wire electrodes are inserted using a 25- or 27-gauge introducer needle, inserted 0.5 cm just beneath the skin, parallel to the scalp. The wire is then held in place while the needle is

removed. The external wires should be coiled to relieve tension and fixed to the scalp using collodion, EC2 paste, cyanoacrylate, or Tegaderm adhesive.

- d. Procedures for patients with nonintact skin: Disposable scalp electrodes may be used but can be expensive. Electrode caps should not be used on nonintact skin. Care should be taken to avoid contamination of surgical wounds, intracranial monitoring devices, or other scalp lesions. In many cases, electrode positions may need to be adjusted to avoid scalp lesions; the homologous electrode over the contralateral hemisphere should also be moved.
4. Number of electrodes
- a. Standard CCEEG requires a minimum of 16 electrodes placed according to the 10-20 International System, with placement designed to optimize brain regions sampled (e.g., Fp1, Fp2, C3, C4, O1, O2, T3, T4). If fewer than 16 electrodes are used, interpretation of CCEEG may be limited by inadequate spatial sampling, inability to distinguish artifact from cerebral activity, and poor quality or uninterpretable studies if any of the few electrodes are dislodged or are contaminated by large amounts of artifact. Studies using hairline and subhairline montages had a sensitivity for seizures of 54% to 72% compared with full EEG (Kolls and Husain, 2007; Tanner et al., 2014; Young et al., 2009).
 - b. Fewer than 16 EEG channels may be used for rapid screening of EEG in emergency situations, but adequate EEG recording (i.e., >16 electrodes) should be instituted as soon as possible.
5. Extracerebral electrodes: At a minimum, electrocardiogram should be recorded with every CCEEG study. Electrooculogram, electromyogram, and respiratory channels (airflow, respiratory effort, and oxygen saturation) are also commonly used. Other physiologic parameters (blood pressure, intracranial pressure, cerebral tissue oxygenation) are often recorded in ICU patients. Integration of these signals with EEG (multimodality monitoring) may improve recognition of neurologic dysfunction and determination of etiology.
6. Montages: Montages should be appropriate for the abnormalities anticipated. Suggestions for montages can be found in other ACNS guidelines (American Clinical Neurophysiology Society 2006c).
- a. Neurodiagnostic technologists should make note of any skull defects including craniotomies, intraventricular drains, bolts, and burr holes and indicate this in the EEG record and report. If the standard 10-20 montage needs to be modified due to skull defects or intracranial equipment, it should be modified symmetrically with adjustment of the corresponding contralateral electrode. This should also be documented in the EEG record and report.
7. EEG quality: Before initiation of recording, the NDT should perform an impedance check and evaluate for presence of artifacts. Because modern amplifiers have high input impedance, electrode impedances less than 10,000 Ω are acceptable.
8. Video and audio: Cameras should be adjusted to allow a full body view of the patient and lighting adjusted to obtain acceptable video quality. Bedside caregivers and family should be encouraged to verbally describe any clinical events that occur.

9. Neurodiagnostic technologists should collect relevant clinical data from ICU staff and the medical record, such as patient history, level of consciousness, recent procedures, medications (including sedatives, paralytics, and antiseizure drugs [ASDs]), and other monitoring techniques in use. Neurodiagnostic technologists should prepare a brief summary of clinical data.
10. Neurodiagnostic technologists should remain at the bedside for the first 20 minutes of recording to evaluate for EEG patterns requiring urgent interpretation, examine patient behavior, and ensure acceptable data quality. During this time, NDTs should perform activation procedures to test reactivity of the EEG: visual stimulus (shine light in patient's eyes), auditory stimulus (clap hands or call name), tactile stimulus (shake limb, nasal tickle), and painful stimulus (sternal rub, nail bed pressure). There are no data regarding the optimal method of reactivity testing.
11. Neurodiagnostic technologists should instruct ICU staff on operation of CCEEG equipment, including type of electrodes used and imaging compatibility, techniques for emergency removal of electrodes if needed, use of the event button and camera controls, instructions for annotating the EEG record or keeping an article log for clinical events, identification of common artifacts, and procedures for contacting EEG staff if technical problems arise.

Daily Maintenance of Critical Care Continuous EEG

1. Neurodiagnostic technologists should collect relevant interim clinical data from ICU staff and prepare interim clinical notes as above.
2. Neurodiagnostic technologists should review operation of CCEEG equipment with ICU staff as needed daily.
3. Critical care continuous EEG recording quality should be checked at least twice daily to identify and correct electrode and other technical artifacts. Impedance should be checked daily, or more often if recording characteristics change. Refilling of the electrodes with conductant gel should be performed as necessary to maintain low impedance. Digital algorithms can be used to identify channels with probable electrode artifact and display the "bad electrodes" on the bedside EEG machine or automatically alert EEG personnel that data quality has deteriorated. If available, ICU nursing staff should be trained to use these displays.
4. The patient's scalp should be inspected daily for evidence of skin breakdown or infection. Programs should have written protocols describing how and when to check for skin breakdown, how to document, to whom skin breakdown should be reported, and methods of treatment.
5. Clinical and EEG reactivity should be assessed daily. The presence of any sedating medications and the timing of their administration should be recorded. Optimally, reactivity testing is performed after fixing any electrode problems. Because fixing electrodes is a type of stimulation, reactivity should be assessed from the time the patient is first stimulated. The stimulus used for reactivity testing should be recorded, and an institutional protocol for reactivity assessment may be useful. For certain indications, such as monitoring for ischemia, more frequent checks of reactivity are helpful and can be incorporated into nursing assessments and annotated on the EEG record.

Electrode Removal and Infection Control

1. Disk electrodes: Collodion is typically removed with acetone, which can cause injury to patient's eyes and mucous membranes. Acetone can also dissolve some plastics and tubing used in other medical devices, such as extracorporeal membrane oxygenation (ECMO) tubing and intraventricular catheters. A nonacetone collodion remover is available but less effective than acetone. EC2 paste can be softened with warm water for 1 to 2 minutes before electrode removal. Electrodes used on nonintact skin or when large amounts of blood are present on scalp require high-level disinfection or sterilization before reuse, either steam sterilization for 5 to 10 minutes or glutaraldehyde (Cidex) soak for 45 minutes.
2. Needle electrodes: Disposable single-use electrodes reduce expense of cleaning and risk of accidental needlesticks during cleaning.
3. Subdermal wire electrodes: Single use disposable.
4. After electrode removal, the patient's hair and scalp should be cleaned thoroughly. The scalp should be inspected for signs of skin breakdown or infection, with notification of nursing and physician staff if present.
5. If CCEEG staff is not available in hospital at all times, there should be a plan for electrode removal if needed (i.e., unexpected urgent neuroimaging), including storage of needed materials in a location where bedside caregivers can access.

Quantitative EEG Techniques

1. We suggest that QEEG trends be incorporated into CCEEG clinical workflows. Quantitative EEG trends cannot be interpreted in isolation from raw EEG. Computer processing of digital EEG data can make CCEEG review less time consuming, may reveal subtle changes in the EEG occurring over long periods of time that would be missed on visual review of raw data (Scheuer and Wilson, 2004), and can produce alerts or alarms to notify staff about changes in EEG patterns. Most QEEG techniques for CCEEG involve calculation of fast Fourier transforms of EEG data into frequency and power measurements, with display over a compressed time scale (hours). Other techniques display rhythmicity, amplitude, or symmetry measures. A variety of graphical displays can be used to improve non-electroencephalographer interpretation of CCEEG (Claassen et al., 2004; Foreman and Claassen, 2012; Pensirikul et al., 2013; Schmidt and Claassen, 2011; Stewart et al., 2010; Zhang et al., 2010). Trends can help in assessment of sleep-wake cycles, recognition of slow changes in EEG activity over time, and identification of specific regions of interest for more detailed review.
2. This consensus statement does not describe all of the QEEG trends that have been used in CCEEG. Density spectral array is a graphical picture of the EEG that compresses hours of activity into time, distribution of frequency, and power measurements. Other graphical displays include color spectrograms (power in each frequency band vs. time), total power in certain frequency bands, ratios of power in certain bands over a broader spectrum of EEG power, envelope trends, amplitude-integrated EEG, and spectral edge displays. Quantitative

EEG trends can be generated for individual EEG channels or combination of channels to provide overviews of homologous left and right brain regions.

3. When QEEG trends are used by non-EEG staff in the ICU to identify changes in brain activity, QEEG and raw EEG changes should be confirmed by expert EEG readers before changes in therapy are initiated. Review of quantitative displays sometimes quickly reveals important EEG changes such as seizures, but the technique is very susceptible to artifact. It is essential that the associated raw EEG be immediately available for review and comparison, to confirm that QEEG changes accurately reflect the ongoing EEG. A practical display is to use dual monitors, with one showing QEEG trends over 1 to several hours and the second showing the raw CEEG tracings at 10 to 20 seconds per page.
4. Quantitative EEG trends should include sufficient EEG channels for adequate spatial sampling of brain activity. As in limited montages for display of raw EEG, QEEG analysis of single or limited channels may miss seizures or events occurring in other brain regions. While such simplified trends may have some utility to identify shivering or monitor depth of sedation in general ICU patients, their sensitivity and specificity in patients with acute neurological injuries is largely unknown (Deogaonkar et al., 2004; Dou et al., 2014; Seder et al., 2010).
5. Quantitative EEG trends can aid in rapid identification and quantification of NCS but may miss seizures, even when reviewed by experienced readers (Anderson and Wisneski, 2008; Pensirikul et al., 2013; Sackellares et al., 2011; Stewart et al., 2010).
 - a. Many seizures in critically ill patients contain rhythmic waveforms in the 2-6 Hz or 6-14 Hz frequency ranges. Seizures are often associated with transient increases in EEG power and are easily recognized on graphical displays of total power in the 6-14 Hz frequency band and in the color spectrogram (Williamson et al., 2014). Seizures shorter than 30 seconds may not be detected if 30-second windows are used for processing. Amplitude-integrated EEG can also be used for seizure identification. Many quantitative techniques can be obscured by any electrode or movement artifact. Use of the envelope trend, a graph of median amplitude in each 30-second epoch, is less susceptible to brief artifacts than graphs of total power. Some commercially available software includes proprietary trends (e.g., cerebral function monitor, rhythmicity spectrograms), which are also useful for seizure identification.
 - b. Current commercially available software allows nearly limitless variations in quantitative techniques, channels, and display methods. Different techniques may be helpful in different patients. Once an electrographic seizure is seen on EEG, quantitative trends can be fine tuned to optimize identification (e.g., specific channels, more restricted frequency bands). Seizure monitoring trends should also include a trend for burst suppression ratio and interburst intervals for monitoring of efficacy of continuous intravenous antiseizure drugs (cIV-ASDs) such as midazolam, propofol, and pentobarbital.
6. Because of the variety of techniques available, no definitive recommendations can be made regarding optimal QEEG trends for seizure identification. Some seizures are better seen on one type of trend than another. Use of

several panels with different types of trends allows interpreters to choose among different views without requiring reprocessing of the data. Time windows for seizure detection trends should be 2 hours at most, and 30- to 60-minute windows are preferred.

7. Quantitative EEG trends can enhance identification of ischemia. Several QEEG trends have been used to identify ischemia, but data are insufficient for strong recommendations. The most useful trends appear to be relative alpha variability (variability in the ratio of alpha power [6–14 Hz] to total EEG power [1–20 Hz]) (Vespa et al., 1997) and the poststimulation alpha-to-delta ratio (ratio of alpha power [6–14 Hz] to delta power [1–4 Hz]) (Claassen et al., 2004). In retrospective analyses, both had excellent sensitivity (89–100%) but only moderate specificity. Channels should be selected to monitor specific vascular territories (e.g., F3–C3 for left anterior cerebral artery, C3–T3 for left middle cerebral artery). Longer time windows (4–12 hours) may aid in identification of slowly developing ischemia.
8. Seizure detection algorithms and automated background assessment: Most automated seizure detection algorithms were developed for ictal patterns seen in patients with established epilepsy and have not been validated in ICU populations with acute symptomatic seizures (Sackellares et al., 2011). Automated analysis of background patterns (e.g., burst suppression periodic patterns) is an active research area but is not in routine clinical use (Cloostermans et al., 2011; Shibasaki et al., 2014; Westover et al., 2013).

EEG and Behavioral Monitoring by Nonphysician Personnel

1. Patients undergoing CEEG monitoring should be observed for key clinical events, such as movements or autonomic changes suggestive of seizures, changes in level of consciousness, potential sources of artifact, and administration of medications and sedation. In addition, EEG should be reviewed as often as logistically and technically feasible (at least twice daily) for data quality and important EEG changes. Behavioral and EEG observation can be performed at the bedside or centrally through hospital networks, and by a variety of ICU and EEG staff. Several possible models of EEG and behavioral monitoring are described below.
2. Bedside ICU staff can document some key clinical events but are not likely to be continuously observing the patient. Intensive care unit staff should be trained to (1) maintain a record of patient behavior, clinical events, and sedative or ASD administration in nursing notes, a bedside log, or directly in the EEG recording, (2) use the event button to indicate suspected seizures, (3) perform tests of reactivity and annotate the EEG record when performed, and (4) notify EEG staff when important clinical changes occur.
3. Video recording (bedside or remote) provides continuous assessment of patient behavior and activities around the patient bedside.
4. Raw EEG tracings (bedside or remote): Review of raw EEG is the most reliable way of identifying seizures and other important changes in EEG patterns. However, review of raw CEEG poses several logistical problems: (1) highly trained staff are required to continuously view the EEG, (2) staff can only review a limited number of CEEGs simultaneously (especially if also observing video streams), and (3) networking and display equipment can be expensive.

5. Quantitative EEG graphical displays can be used both bedside and remotely to alert ICU staff of important changes in the EEG. These allow review of longer segments of EEG, decreasing the need for second-by-second attention to the EEG tracing.
6. Central continuous monitoring: This is the optimal means of correlating behavior with EEG features, assessing possible sources of artifact, and identifying acute changes in EEG features suggestive of neurologic deterioration. Although some CCEEG centers can perform many aspects of central continuous monitoring, the majority of centers cannot currently provide this level of real-time review.
 - a. Patient behavior and activities around the patient bedside are recorded continuously on video and audio time-synchronized to EEG.
 - b. Events and automated event detection: Events of interest by patient or observer pushbutton or automated computer analysis of EEG (spike and seizure detection, QEEG trends) generate “alerts” (audio, pager, and e-mail) for bedside ICU staff and EEG staff.
 - c. Raw EEG may be continuously viewable.
 - d. Graphical displays of QEEG can be incorporated into monitoring. These can include both trends over time and other processed data such as “bad electrode” displays.
 - e. Real-time assessment of EEG and video data optimizes the likelihood of early identification of EEG changes, and annotations may improve the efficiency of physician review and reporting. This system requires specialized equipment for recording and display of video, EEG, and QEEG and is therefore expensive.
 - f. Types of observation
 1. EEG review: EEG should be reviewed intermittently or continuously. The raw EEG traces are reviewed, typically with simultaneous video, and often supplemented by QEEG trends. Experienced NDTs are specially trained to identify clinical changes, EEG patterns, and QEEG patterns that may indicate seizures and other neurologic events. Neurodiagnostic technologists frequently or continuously review EEG, video, and QEEG trends, annotate the recording, highlight segments for later physician review, and notify physician electroencephalographers when significant changes in EEG occur. Use of NDTs as observers requires adjustment in staffing patterns for EEG laboratories (weekend and night shifts). Optimally, at least one NDT should be assigned to EEG monitoring exclusive of all other duties, so that recordings are truly monitored continuously. If large numbers of patients are monitored, additional staff may be needed. A practical ratio of 1 NDT to 4–8 patients is suggested, although there are no data on the optimal technologist-to-patient ratio. Use of NDTs limits the number of potential false positive reports to physicians interpreting EEGs.
 2. Video and QEEG trend review: Specially trained patient observers can identify clinical events on video, and can also be trained to recognize changes in QEEG, but are not expert in EEG pattern recognition and cannot substitute for NDTs. Electroencephalographers would need to review all EEG tracings before clinical recommendations are

made, and use of staff who are less familiar with EEG may result in large numbers of false positive notifications.

7. Remote monitoring (out-of-hospital): Technological advances now allow review of ongoing EEG recordings from remote locations, although remote real-time video review is still difficult. Critical care continuous EEG requires a team approach, specific expertise, and a high level of communication between EEG and ICU personnel. Remote access and monitoring employing qualified personnel as described in RESPONSIBILITIES OF CRITICAL CARE CONTINUOUS EEG PERSONNEL might be used to supplement a hospital-based CCEEG team but does not itself satisfy all recommendations for CCEEG.

Review, Interpretation, and Reports

1. There are widely variable practices for review and reporting of CCEEG, depending on local resources (Abend et al., 2010). Several options are described below. Each CCEEG program should develop and follow written policies and procedures for CCEEG review and reporting, adapted for local availability of equipment and staff. Remote access to the EEG tracings facilitates timely interpretation.
2. Critical care continuous EEG should be reviewed frequently by trained NDTs for technical quality and by electroencephalographers for important events, at a minimum twice daily. The first 30–60 minutes of EEG recording should be reviewed and interpreted as soon as possible, with results conveyed to the clinical care team. In some centers, this initial review is performed by neurology trainees, ICU physicians with training in EEG, clinical neurophysiology trainees, or attending EEG staff. In other centers, NDTs summarize and annotate the EEG record, which is reviewed by attending EEG staff. In all cases, the responsible attending EEG physician should be available for confirmation of any important EEG findings noted by other reviewers. More frequent review should be performed as indicated by the CCEEG findings, the patient’s clinical status, and the occurrence of any clinical events.
3. Daily reports should be generated by physician electroencephalographers to allow timely clinical correlation of the CCEEG findings. Written reports should be written at least daily and should clearly describe any EEG, QEEG, and video events. Interim written or verbal reports should be issued to the clinical care team when important changes occur. Reports generally include (1) patient identifying information, (2) recording techniques used, (3) reason for monitoring and patient history, (4) interim clinical changes for multi-day studies, (5) relevant medications, including dose and duration of any ASDs, (6) duration of monitoring, (7) description of background EEG patterns, including presence or absence of periodic and rhythmic patterns and presence or absence of reactivity, (8) interpretation of clinical and/or EEG events (e.g., seizures) individually or collectively, (9) description of QEEG trends if used, (10) overall impression or summary of findings, and (11) clinical correlation. A wide variety of patterns can be seen in CCEEG studies; use of standardized terminology for EEG reports may improve interreader agreement (Gaspard et al., 2014; Hirsch et al., 2013).

4. Communication with the clinical team: To provide the most useful interpretation to the clinical team, it is helpful to have daily updates of the patient's clinical status, including level of alertness, medications initiated or discontinued, interim procedures, and results of testing such as CT, MRI, and Transcranial Doppler imaging. Computerized medical records can be reviewed if available. Alternatively, nurses and physicians can enter information into the EEG machine itself. Results of CCEEG should be transmitted to the clinical care team as soon as available. In addition to written reports, this often involves phone discussions or multidisciplinary team rounds, which should be documented in the patient's medical record.
5. Critical care continuous EEG electroencephalographers should consider using a database to track the utilization and utility of CCEEG in their own institution. Critical care continuous EEG is an expensive and labor-intensive procedure, with rapidly evolving indications and technical specifications. Tracking the number and duration of studies, indications and diagnoses, and proportions of studies showing seizures or other clinically important findings allows centers to modify their practice to meet local needs.

Critical Care Continuous EEG Data Storage Protocols

1. Storage for initial analysis: All video/audio data and EEG data should be saved until appropriately analyzed and reported by trained personnel. After CCEEG review, data can be reduced by (1) selection of pertinent video segments (clinical and EEG events), and then deletion of all other video but retention of entire EEG, or (2) selection of pertinent video and EEG segments (baseline background, clinical and EEG events), and then deletion of the remainder of EEG and video data. The first option may be more appropriate when QEEG trends are used and also minimizes the amount of time that NDTs spend annotating and clipping data. Edited data to be stored should include a short period (approximately 2 minutes) before and after any events, as well as the entire episode. A log of the contents of all edited data should be maintained, preferably as part of the detailed report. If QEEG trends are used for interpretation, these trends should be stored with the EEG study as they were viewed during interpretation.
2. Archival storage: Video and EEG data can be archived to digital media, including DVDs, external hard drives, archive servers, and network-attached storage devices. Each CCEEG monitoring center should consult their institutional and/or state guidelines for the mandated duration of data storage. Legal counsel may be required if established guidelines are lacking. In most instances, EEG recordings should be stored for 7 years or until pediatric patients reach 18 years of age, whichever is longer.
3. Data formats and transmission: Ideally, EEG data should be able to be recorded and stored in nonproprietary or publicly available formats to ensure that data can be viewed outside the manufacturer's proprietary software (American Clinical Neurophysiology Society, 2008). For practical reasons, most EEG is recorded and stored in a proprietary format, with conversion to open formats only if needed.

CONCLUSIONS

Critical care continuous EEG is an emerging technique to identify secondary brain injuries such as seizures and ischemia in critically ill patients. Critical care continuous EEG is distinct from video-EEG monitoring for epilepsy, in terms of both equipment and personnel, and requires specialized training and protocols. While the current standard in most centers is continuous recording with intermittent review and interpretation, advances in technology are facilitating real-time review. Optimal performance of CCEEG requires a collaborative team approach between CCEEG staff and bedside ICU caregivers, with frequent communication regarding changes in clinical status and in EEG.

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REFERENCES

- Abend NS, Dlugos DJ, Hahn CD, et al. Use of EEG monitoring and management of non-convulsive seizures in critically ill patients: a survey of neurologists. *Neurocrit Care* 2010;12:382–389.
- American Clinical Neurophysiology Society. Guideline 1: minimum technical requirements for performing clinical electroencephalography. *J Clin Neurophysiol* 2006a;23:86–91.
- American Clinical Neurophysiology Society. Guideline 2: minimum technical standards for pediatric electroencephalography. *J Clin Neurophysiol* 2006b;23:92–96.
- American Clinical Neurophysiology Society. Guideline 6: a proposal for standard montages to be used in clinical EEG. *J Clin Neurophysiol* 2006c;23:111–117.
- American Clinical Neurophysiology Society. Guideline 8: guidelines for recording clinical EEG on digital media. *J Clin Neurophysiol* 2006d;23:122–124.
- American Clinical Neurophysiology Society. Technical standard 1: standard for transferring digital neurophysiological data between Independent computer systems. <http://www.acns.org/pdf/guidelines/Technical-Standard-1.pdf>. Retrieved October 1, 2014.
- American Society of Electroneurodiagnostic Technologists I. National competency skill standards for ICU/cEEG monitoring. *Am J Electroneurodiagnostic Technol* 2008;48:258–264.
- Anderson NR, Wisneski KJ. Automated analysis and trending of the raw EEG signal. *Am J Electroneurodiagnostic Technol* 2008;48:166–191.
- Claassen J, Hirsch LJ, Kreiter KT, et al. Quantitative continuous EEG for detecting delayed cerebral ischemia in patients with poor-grade subarachnoid hemorrhage. *Clin Neurophysiol* 2004;115:2699–2710.
- Cloostermans MC, de Vos CC, van Putten MJ. A novel approach for computer assisted EEG monitoring in the adult ICU. *Clin Neurophysiol* 2011;122:2100–2109.
- Deogaonkar A, Gupta R, DeGeorgia M, et al. Bispectral Index monitoring correlates with sedation scales in brain-injured patients. *Crit Care Med* 2004;32:2403–2406.
- Dou L, Gao HM, Lu L, Chang WX. Bispectral index in predicting the prognosis of patients with coma in intensive care unit. *World J Emerg Med* 2014;5:53–56.
- Epstein CM. Aliasing in the visual EEG: a potential pitfall of video display technology. *Clin Neurophysiol* 2003;114:1974–1976.
- Foreman B, Claassen J. Quantitative EEG for the detection of brain ischemia. *Crit Care* 2012;16:216.
- Gaspard N, Hirsch LJ, LaRoche SM, et al. Interrater agreement for critical care EEG terminology. *Epilepsia* 2014;55:1366–1373.
- Hartings JA, Bullock MR, Okonkwo DO, et al. Spreading depolarizations and outcome after traumatic brain injury: a prospective observational study. *Lancet Neurol* 2011;10:1058–1064.
- Hartings JA, Wilson JA, Look AC, et al. Full-band electrocorticography of spreading depolarizations in patients with aneurysmal subarachnoid hemorrhage. *Acta Neurochir Suppl* 2013;115:131–141.
- Hirsch LJ, LaRoche SM, Gaspard N, et al. American clinical neurophysiology society's standardized critical care EEG terminology: 2012 version. *J Clin Neurophysiol* 2013;30:1–27.
- Ives JR. New chronic EEG electrode for critical/intensive care unit monitoring. *J Clin Neurophysiol* 2005;22:119–123.
- Kolls BJ, Husain AM. Assessment of hairline EEG as a screening tool for nonconvulsive status epilepticus. *Epilepsia* 2007;48:959–965.

- Kolls BJ, Olson DM, Gallentine WB, et al. Electroencephalography leads placed by nontechnologists using a template system produce signals equal in quality to technologist-applied, collodion disk leads. *J Clin Neurophysiol* 2012;29:42–49.
- Kolls BJ, Lai AH, Srinivas AA, Reid RR. Integration of EEG Lead placement templates into traditional technologist-based staffing models reduces costs in continuous video-EEG monitoring service. *J Clin Neurophysiol* 2014;31:187–193.
- Martz GU, Hucek C, Quigg M. Sixty day continuous use of subdermal wire electrodes for EEG monitoring during treatment of status epilepticus. *Neurocrit Care* 2009;11:223–227.
- Miller CM. Update on multimodality monitoring. *Curr Neurol Neurosci Rep* 2012;12:474–480.
- Mirsattari SM, Lee DH, Jones D, et al. MRI compatible EEG electrode system for routine use in the epilepsy monitoring unit and intensive care unit. *Clin Neurophysiol* 2004;115:2175–2180.
- Pensirikul AD, Beslow LA, Kessler SK, et al. Density spectral array for seizure identification in critically ill children. *J Clin Neurophysiol* 2013;30:371–375.
- Quigg M, Shneker B, Domer P. Current practice in administration and clinical criteria of emergent EEG. *J Clin Neurophysiol* 2001;18:162–165.
- Sackellares JC, Shiau DS, Halford JJ, et al. Quantitative EEG analysis for automated detection of nonconvulsive seizures in intensive care units. *Epilepsy Behav* 2011;22(suppl 1):S69–S73.
- Sanchez SM, Arndt DH, Carpenter JL, et al. Electroencephalography monitoring in critically ill children: current practice and implications for future study design. *Epilepsia* 2013a;54:1419–1427.
- Sanchez SM, Carpenter J, Chapman KE, et al. Pediatric ICU EEG monitoring: current resources and practice in the United States and Canada. *J Clin Neurophysiol* 2013b;30:156–160.
- Scheuer ML, Wilson SB. Data analysis for continuous EEG monitoring in the ICU: seeing the forest and the trees. *J Clin Neurophysiol* 2004;21:353–378.
- Schmidt JM, Claassen J. Can quantitative EEG reliably predict deterioration from delayed cerebral ischemia secondary to vasospasm? *Neurocrit Care* 2011;14:149–151.
- Seder DB, Fraser GL, Robbins T, et al. The bispectral index and suppression ratio are very early predictors of neurological outcome during therapeutic hypothermia after cardiac arrest. *Intensive Care Med* 2010;36:281–288.
- Seiler L, Fields J, Peach E, et al. The effectiveness of a staff education program on the use of continuous EEG with patients in neuroscience intensive care units. *J Neurosci Nurs* 2012;44:E1–E5.
- Shibasaki H, Nakamura M, Sugi T, et al. Automatic interpretation and writing report of the adult waking electroencephalogram. *Clin Neurophysiol* 2014;125:1081–1094.
- Stewart CP, Otsubo H, Ochi A, et al. Seizure identification in the ICU using quantitative EEG displays. *Neurology* 2010;75:1501–1508.
- Stuart RM, Waziri A, Weintraub D, et al. Intracortical EEG for the detection of vasospasm in patients with poor-grade subarachnoid hemorrhage. *Neurocrit Care* 2010a;13:355–358.
- Stuart RM, Schmidt M, Kurtz P, et al. Intracranial multimodal monitoring for acute brain injury: a single institution review of current practices. *Neurocrit Care* 2010b;12:188–198.
- Tanner AE, Sarkela MO, Virtanen J, et al. Application of subhairline EEG montage in intensive care unit: comparison with full montage. *J Clin Neurophysiol* 2014;31:181–186.
- Tatum WO, Dworetzky BA, Freeman WD, Schomer DL. Artifact: recording EEG in special care units. *J Clin Neurophysiol* 2011;28:264–277.
- Vespa PM. Multimodality monitoring and telemonitoring in neurocritical care: from microdialysis to robotic telepresence. *Curr Opin Crit Care* 2005;11:133–138.
- Vespa PM, Nuwer MR, Juhasz C, et al. Early detection of vasospasm after acute subarachnoid hemorrhage using continuous EEG ICU monitoring. *Electroencephalogr Clin Neurophysiol* 1997;103:607–615.
- Vulliamoz S, Perrig S, Pellise D, et al. Imaging compatible electrodes for continuous electroencephalogram monitoring in the intensive care unit. *J Clin Neurophysiol* 2009;26:236–243.
- Wartenberg KE, Schmidt JM, Mayer SA. Multimodality monitoring in neurocritical care. *Crit Care Clin* 2007;23:507–538.
- Waziri A, Claassen J, Stuart RM, et al. Intracortical electroencephalography in acute brain injury. *Ann Neurol* 2009;66:366–377.
- Westover MB, Ching S, Shafi MM, et al. Real-time segmentation and tracking of brain metabolic state in ICU EEG recordings of burst suppression. *Conf Proc IEEE Eng Med Biol Soc* 2013;2013:7108–7111.
- Williamson CA, Wahlster S, Shafi MM, Westover MB. Sensitivity of compressed spectral arrays for detecting seizures in acutely ill adults. *Neurocrit Care* 2014;20:32–39.
- Young GB, Sharpe MD, Savard M, et al. Seizure detection with a commercially available bedside EEG monitor and the subhairline montage. *Neurocrit Care* 2009;11:411–416.
- Zhang J, Xanthopoulos P, Liu CC, et al. Real-time differentiation of non-convulsive status epilepticus from other encephalopathies using quantitative EEG analysis: a pilot study. *Epilepsia* 2010;51:243–250.
- Ziai WC, Schlattman D, Llinas R, et al. Emergent EEG in the emergency department in patients with altered mental states. *Clin Neurophysiol* 2012;123:910–917.